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MULTIDISCIPLINARY RESEARCH LEADING TO
UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Annual Status Report
Fiscal Year 1972

TWIN CITIES MINING RESEARCH CENTER

Thomas C. Atchison, Research Director

NASA Contract R-09-040-001

MULTIDISCIPLINARY RESEARCH LEADING TO UTILIZATION OF EXTRATERRESTRIAL RESOURCES

Annual Status Report
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U.S. Bureau of Mines NASA Program of Multidisciplinary Research Leading to Utilization of Extraterrestrial Resources

ANNUAL STATUS REPORT FISCAL YEAR 1972

Contents

ANNUAL STATUS REPORT FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research
Leading to Utilization of Extraterrestrial Resources

July 1, 1972

Task title:	Background analysis and coordination		
Investigator:	David E. Fogelson, Program Manager		
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota		
Date begun:	April 1965	To be completed:	Continuing
Personnel:	David E. Fogelson, Supervisory Geophysicist Other Bureau personnel, as assigned		

PROGRESS REPORT

Objective

The objective of the program is to help provide basic scientific and engineering knowledge needed to use extraterrestrial mineral resources in support of future space missions. Under this component, background and supporting studies and coordinating and liaison activities for the program are carried out.

Summary

During the year the four research tasks at the three research centers making up the Bureau's extraterrestrial resource utilization program were monitored. We continued to obtain, evaluate, and distribute information applicable to the program by literature search and direct contact with groups conducting related research. We also continued to extract and organize material from Bureau reports to provide periodic status reports to NASA and prepared special information related to the program when requested by NASA.

Two proposals were submitted to NASA. One proposal was prepared for continuation of the present program funded under the Office of Advanced Research and Technology (OART) and the other proposal was prepared as requested for the Manned Spacecraft Center (MSC), Houston, Texas, and was concerned with the development of a pilot plant for production of water from simulated lunar material.

Progress During the Year

The past year's effort focused on four tasks with primary emphasis on basic studies of material properties and behavior in a simulated lunar environment. A fifth task on gravity flow of granular materials planned to start in the fourth quarter was canceled. Similar studies will be pursued under a new 2-year program with NASA concerned with production of water from simulated lunar material if funds are made available. Technical information and guidance were provided to the task investigators during the year.

Arrangements were made with Dr. Jack Green, University of Southern California, to study basalt casting as a means of utilizing lunar rocks in the construction of manned bases. Dr. Green has completed the casting of raw basalt samples at three different rates of cooling (1 day, 1 week, 1 month) and also the casting of samples containing 10 percent calcium bicarbonate and 10 percent potassium bicarbonate at the same cooling rates. A report will be prepared by Dr. Green on the results of this study when property measurements being made by the Twin Cities Mining Research Center are completed.

At the request of the MSC, Houston, Texas, D. E. Fogelson, C. W. Schultz, and D. P. Lindroth prepared a proposal titled "Development and Demonstration of a Pilot Plant for Production of Water From Simulated Lunar Material." This program involves several organizations including the University of Minnesota, private contractors, Twin Cities Metallurgy Research Center, Spokane Mining Research Center, and the Twin Cities Mining Research Center.

A proposal for continuation of the present program funded under the OART was also prepared. This proposal was not funded and the research underway will be completed using the carryover funding ($66,000) available for FY 73.

Status of Manuscripts

Proposal for Continuing Bureau Extraterrestrial Resource Utilization Program by D. E. Fogelson and NASA Project Leaders was submitted to NASA in December.

Proposal for Development and Demonstration of a Pilot Plant for Production of Water From Simulated Lunar Material by D. E. Fogelson, C. W. Schultz, and D. P. Lindroth was submitted to NASA in June.

ANNUAL STATUS REPORT FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Surface properties of rocks in simulated lunar environment
Investigator:	Wallace W. Roepke, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	April 1966 To be completed: June 1973
Personnel:	William H. Engelmann, Supervisory Research Chemist Wallace W. Roepke, Principal Vacuum Specialist

PROGRESS REPORT

Objective

The objective of this project is to study the surface properties of rocks and minerals in a simulated lunar environment. The study encompasses friction between ultraclean mineral-mineral pairs, drilling of rock, and vane shear tests, all performed in ultrahigh vacuum (UHV).

Summary

The friction experiments centered around 11 types of minerals tested against an alumina probe at room temperature. UHV produced a 125 to 355 percent increase in the kinetic coefficient of friction (μ_k), over that of atmosphere, when both were run at room temperature. Tests in UHV at lunar day temperatures (135° C) produced a 50 to 100 percent increase in μ_k, over that of room temperature atmospheric tests.

The vane shear work has been completed and a Report of Investigations is in review stage at this time.

The drill rig system is being refurbished for the final drilling tests in UHV.

Progress During the Year

In the friction experiments, a total of 11 sample pairs have been tested in UHV at room temperature this year. Each pair consisted of an alumina probe and one of the following materials: basalt, magnetite, quartz, andesine, dacite, pyroxene, white feldspar, pink feldspar, labradorite, and two types of stainless steel. A 125 to 355 percent increase in the kinetic coefficient of friction (μ_k) was observed in UHV, as compared to tests run in atmosphere. No special cleaning techniques were used on these test pairs, other than normal system bakeout.

Several series of tests have been run at 135° C (lunar "day" temperature) in UHV with a large reduction in μ_k, compared to the room temperature tests. If atmospheric tests at room temperature are taken as the comparative baseline, then these lunar day tests in UHV show only a 50 to 100 percent increase in μ_k compared to the 125 to 355 percent increase in μ_k when run in UHV at room temperature.

Mechanical modifications made on the system in the third quarter improved the system greatly. Improved bearings were used and also complete elimination of backlash in the driving mechanism for the sample wheel was achieved. The backlash did not become critical until the sample heater system had been designed and installed for lunar "day" temperature tests. The higher temperature caused both bearing problems and backlash.

The vane shear testing of simulated lunar particulate material has been completed. A Report of Investigations is being prepared as the final report of this task.

The transfer of James R. Blair in August and of Bradley V. Johnson in November to other projects left this project with some extreme scheduling difficulties. The freeze in hiring left the project leader as the only available team member. With the project badly understaffed, many of the proposed commitments had to be extended or postponed. The drilling studies were therefore suspended for most of the year. In the last quarter, work emphasis was shifted from friction to drilling experiments. The drilling system had been used for the vane shear testing earlier by replacing the drill string with the shear head and providing a suitable sample container. Since the shear work used a fine powder, and the bearings could not be protected from it, it was decided to completely refurbish the drill rig with new bearings, new universal joints, and a newly designed rotary feedthrough. Reassembly is progressing smoothly at this time.

Status of Manuscripts

Suppression of Mass Spectrometer Generated Interference on a Nude Bayard-Alpert Gauge in UHV by W. W. Roepke and K. G. Pung, a Journal article, is in field review.

Shear Testing of Simulated Lunar Soil in Ultrahigh Vacuum by B. V. Johnson, W. W. Roepke, and K. C. Strebig, a Report of Investigations, is in station review.

ANNUAL STATUS REPORT FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Rock failure processes and strength and elastic properties in simulated lunar environment
Investigator:	John O. Atkins, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	June 1966 To be completed: June 1973

Personnel:	S. S. Peng, Mining Engineer John O. Atkins, Physicist Stephen D. Anderson, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this project is to study the effect of simulated lunar environment on rock deformation and failure processes at the mesostructural and the microstructural level. The engineering data obtained from simulated lunar rocks under these environmental conditions will assist advance planning of lunar resource utilization.

Summary

Several series of compression tests were completed on rock specimens in ultrahigh vacuum (UHV). Specimens of dacite, tholeiitic basalt, and Duluth Gabbro were tested in UHV at the lunar "day" temperature (135^{0} C) and at room temperature ($\approx$ 20^{0} C). Pumice specimens were tested in UHV at room temperature. A series of tests on vesicular basalt specimens in UHV at room temperature is currently in progress.

Progress During the Year

Compression Tests in Ultrahigh Vacuum

The cylindrical specimens of Duluth Gabbro, pumice, and vesicular basalt were cored from single blocks in the high, medium, and low velocity directions as determined by measuring acoustic pulse velocities in a sphere prepared from each block. The tholeiitic basalt block was found to be acoustically isotropic and these specimens were all cored from an unspecified common direction. The dacite specimens were cored in the low velocity direction.

Table 1 shows the results of the compression tests made in UHV for which the data have been analyzed. A decrease in the average value of the compressive strength and an increase in the average value of Young's modulus were observed for each rock type as the specimen temperature was increased from 20° to 135° C. Also shown are the variations in these properties with the orientation of the Duluth Gabbro specimens. Compression tests will be made in FY 73 on similar specimens in atmosphere for comparison with the UHV results.

TABLE 1. - Average values of compressive strength and Young's modulus for specimens tested in UHV

Rock type	Orientation	Compressive strength, psi		Young's modulus, x 10^6 psi	
		20° C	135° C	20° C	135° C
Dacite	Low	11,450	10,640	3.04	3.41
Basalt		60,250	58,730	8.58	8.99
Duluth	Low	40,100		12.8	
Gabbro	Medium	45,530	38,070	12.8	13.3
	High	49,130		13.4	

The ranges in chamber pressure (monitored with a nude Bayard-Alpert ionization gage) at the initiation of compressive loading for different specimens of various rock types are shown in table 2.

TABLE 2. - Chamber pressures at initiation of compression tests on three rock types

Rock type	Pressure-torr	
	20° C	135° C
Dacite	Mid to high 10^{-11}	Low to mid 10^{-9}
Basalt	High 10^{-11} to low 10^{-10}	High 10^{-9} to low 10^{-8}
Duluth Gabbro	Low 10^{-11} to low 10^{-10}	Mid 10^{-10}

Apparatus was designed and fabricated for compression testing of rock specimens at the lunar "night" temperature ($\approx$ -185° C) in UHV. Design of apparatus for lunar "day-night" temperature cycling compression studies is nearing completion. This apparatus will provide automatic closed-loop control of rock specimen temperature and rate of change of rock specimen temperature in UHV, thereby allowing a specimen to be exposed in UHV to accelerated lunar temperature cycling. Fabrication and testing of some components of this apparatus has begun. The testing performed to date indicates that some minor design changes will be necessary which will delay the completion of this apparatus to FY 73.

Fabric Analysis

An analysis of fabric in dunite specimens was made by Fabric Analysis Research. The orientations of the x, y, and z optical indicatrix axes for 100 olivine grains were determined on a universal stage and were plotted as equal angle scatter diagrams. These diagrams reveal a preferred orientation of the olivine grains. The orientation of microfractures in dunite was determined both by a universal stage study and by a defect frequency orientation of the microcracks. A preliminary examination of these results shows a correlation between the symmetry of the dunite fabric and the sonic pulse velocity and relative amplitude symmetry (Bur and Hjelmstad)[1].

An analysis of fabric in Duluth Gabbro specimens revealed a preferred orientation of the plagioclase feldspar crystals which compose 50 percent of the rock. The feldspar crystals were found to be oriented with their (010) albite twin composition planes approximately parallel to each other and normal to the high velocity direction. Pyroxene, which composes 35 percent of the rock, was found to be randomly oriented. The remaining 15 percent of the rock was composed of magnetite, olivine, serpentine, and pyrite, none of which occurred in sufficient abundance to allow a thorough orientation analysis. Examination of microfracture orientations in the plagioclase feldspar revealed no preferred orientation throughout the bulk specimen.

The results of these fabric studies will be compared to the results of the acoustic and compression studies as a means for indicating the effects of the various environmental conditions on the mechanism of rock failure.

1 Bur, Thomas R., and Kenneth E. Hjelmstad. Elastic and Attenuation Symmetries of Simulated Lunar Rocks. Icarus, v. 13, No. 3, Nov. 1970, pp. 414-423.

Status of Manuscripts

Effect of Moisture and Temperature on the Fracture Morphology of Dacite by R. J. Willard and K. E. Hjelmstad was published in the International Journal of Rock Mechanics and Mining Sciences, v. 8, No. 6, Nov. 1971, pp. 529-539.

Environmental Effects of Rock Properties by E. R. Podnieks, P. G. Chamberlain, and R. E. Thill, presented at the 10th Symposium on Rock Mechanics, May 20-22, 1968, was published in the Proceedings, 1972, pp. 215-241.

ANNUAL STATUS REPORT FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Thermal fragmentation and thermophysical and optical properties in simulated lunar environment
Investigator:	David P. Lindroth, Project Leader
Location:	Twin Cities Mining Research Center Minneapolis, Minnesota
Date begun:	July 1971 To be completed: June 1973
Personnel:	Kuppusamy Thirumalai, Supervisory Mining Engineer David P. Lindroth, Physicist James R. Blair, Physical Science Technician

PROGRESS REPORT

Objective

The objective of this work is to study the problems of thermal fragmentation in lunar environment. Through the use of nondestructive testing and remote sensing technology, the thermophysical properties of simulated lunar rocks are to be determined as a function of temperature and pressure over the lunar environment range. A study on the optical properties of absorptance, reflectance, and the absorption coefficient as a function of wavelength and temperature will be made.

Summary

During the year, work was completed on the system design and modifications, sample preparation, and the standardization and calibration of the system. The thermal diffusivity measurements on tholeiitic basalt were completed.

Progress During the Year

During the first quarter, emphasis was placed on system design and modifications and sample preparation. The gear box, bearing assembly, and gears for driving the multispecimen sample holder were redesigned to provide more torque and more accurate alignment. The machining and heliarc welding were completed early in the second quarter.

In order to provide an independent rough pumping capability and minimize pump down times, a foreline was designed to be an integral part of the ultrahigh vacuum system (UHV). The foreline (6 in long, 1-1/2 in-OD tube) contains a sorption pump and a UHV valve, a thermocouple gage, and an up-to-atmosphere valve for rough pumping. The heliarc welding of the thermocouple gage and up-to-atmosphere valve on the foreline was completed early in the second quarter and the finished foreline was mounted on the UHV system (fig. 1). A Bell and Gossett oil-less vacuum pump was obtained for rough pumping.

Custom-made and mounted Germanium windows were ordered for the system to eliminate the leak problems encountered earlier with the windows fabricated in-house. These were obtained in the second quarter and mounted on the UHV system. A window which transmits the visible wavelengths was mounted on the system to aid in alignment of the samples while under UHV. Also, a stainless steel screen was mounted inside and at the base of the chamber above the ion pump throat to confine the pump's glow discharge to the pump area and eliminate potential dropping of parts into the ion pump.

Having been plagued for the previous 6 months with various small leaks, which had limited the ultimate pressure to 10^{-6} torr, a flange adapter was ordered in the first quarter to allow coupling a mass spectrometer head to the UHV system. In the meantime, a crack in a weld on one of the 1-1/2-in-diameter ports was discovered. The system was shipped back to the company for repair late in October. The repaired system was returned the third week in November, was checked out and determined to be in working order again. The flange adapter for the mass spectrometer head was received and the mass spectrometer head was mounted on the chamber. Using the mass spectrometer, relative gas ratios at baseline conditions were established on the chamber in the clean, dry, and empty condition.

The sample preparation of the six rock types required for the diffusivity measurements was completed early in the second quarter. Forty, 19-mm-diameter disks, varying from 2 to 8 mm thick, were cut and polished for each of the following rock types: Duluth Gabbro, dunite, obsidian, granodiorite, and tholeiitic basalt.

A sample of Corning fused silica (No. 7940) was obtained for use as a standard. The preparation of thin disks of this material was delayed because of problems encountered in fitting a larger diameter, thin wall diamond core drill to the existing drill. Machining on a special chuck for the drill was finally completed early in the third quarter. Cores were drilled out of the standard and disks were prepared from the cores. The standardization and calibration runs were completed by the end of the third quarter.

Electronic noise problems were encountered early in the year with the radiometer but were solved by passing the output signal through a solid state variable filter. Runs were made to determine the effect of filtering on the transient temperature slope and to select optimum filter settings.

During the time lost by shipping the UHV chamber back to the manufacturer and waiting for the fused silica standard sample, runs were made on two samples of Dresser basalt at ambient temperature and pressure. The thermal properties on this particular sample of basalt have been previously established and our measurements by the flash method gave thermal diffusivity values which varied by ± 5 percent or less from the previously established values. Also, runs made on the fused silica standard sample gave diffusivity values within the ± 5 percent uncertainty given for the standard.

During the third quarter the equipment was moved to the new Thermal Fragmentation annex laboratory (Building 205). Figure 2 shows the overall test setup for diffusivity measurements.

Due to the delays incurred during the year, the diffusivity measurements on the six simulated lunar rock types are behind schedule. Only the measurements on tholeiitic basalt have been completed. We anticipate that the remaining measurements on five rock types will be completed during the first quarter of FY 1973 and a report initiated at that time.

Status of Manuscripts

Delayed until September.

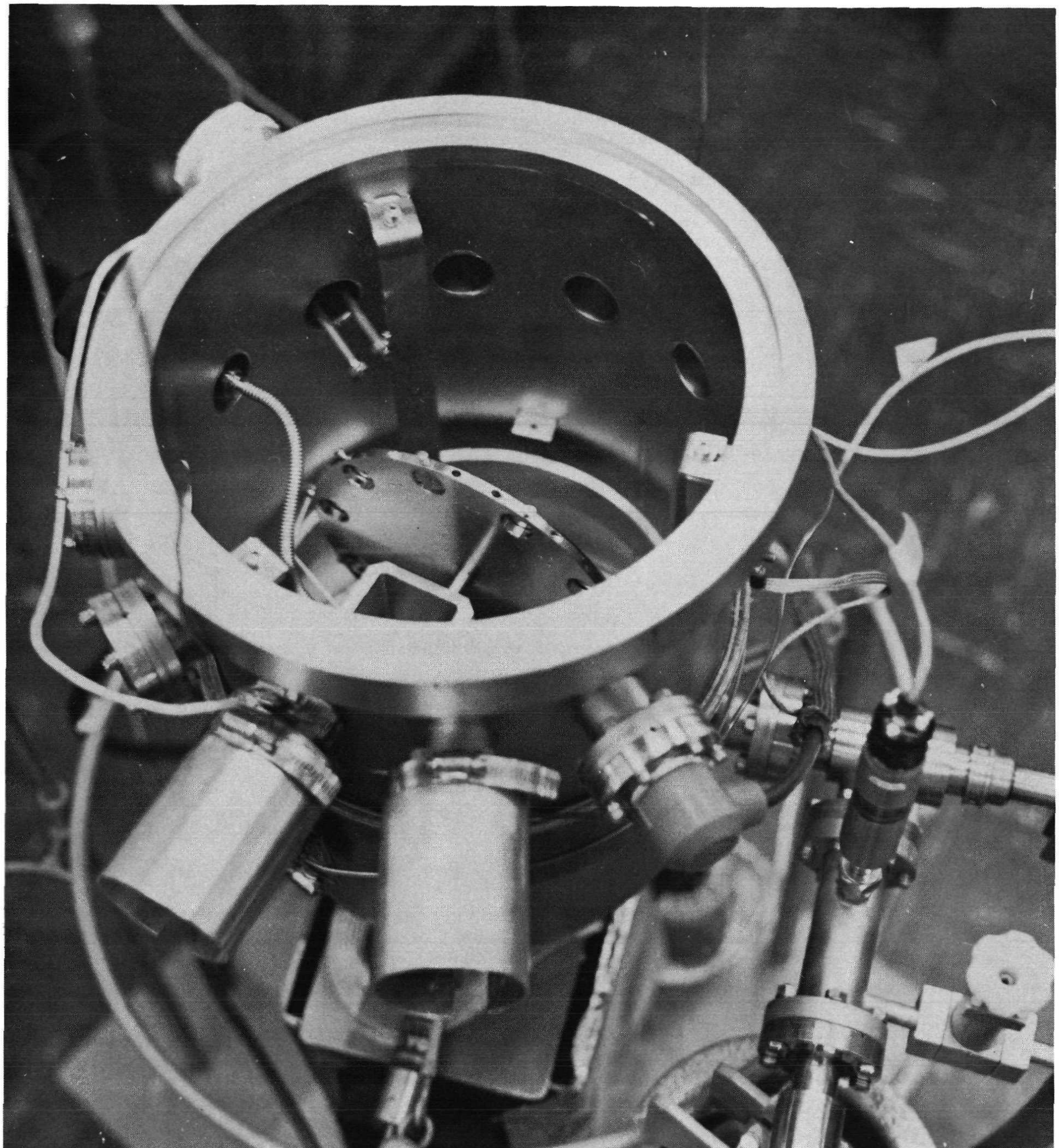

FIGURE 1. - Multispecimen Sample Holder Mounted in UHV Chamber.

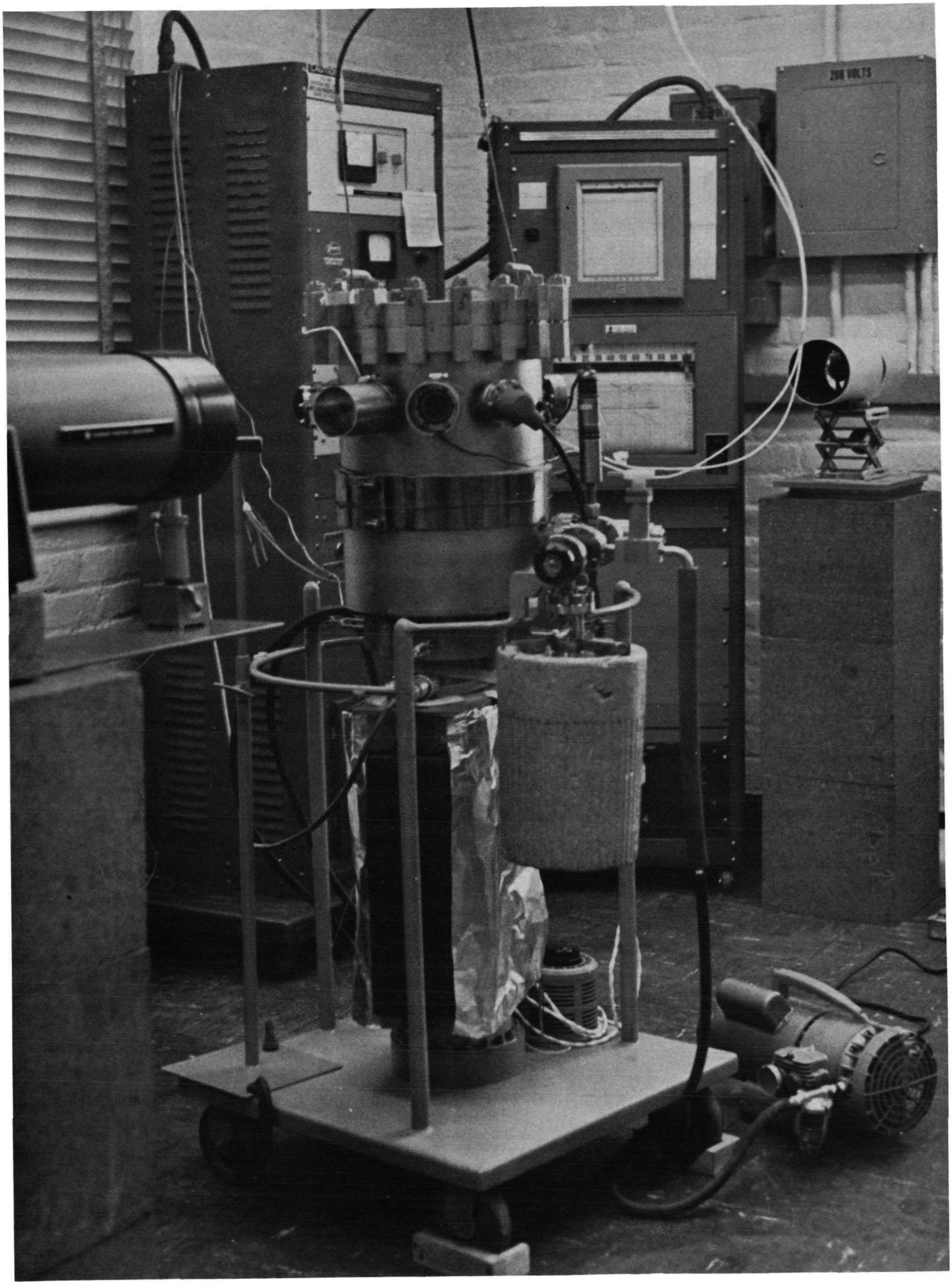

FIGURE 2. - Test Setup for Diffusivity Measurements in Ultrahigh Vacuum.

ANNUAL STATUS REPORT FISCAL YEAR 1972

U.S. Bureau of Mines NASA Program of Multidisciplinary Research

Task title:	Use of explosives on the moon
Investigator:	J. Edmund Hay, Project Leader
Location:	Pittsburgh Mining and Safety Research Center Pittsburgh, Pennsylvania
Date begun:	July 1966 To be completed: June 1973
Personnel:	Richard W. Watson, Supervisory Research Physicist J. Edmund Hay, Research Physicist Robert M Swetkis, Physical Science Technician Joseph Ferrelli, Physical Science Aid

PROGRESS REPORT

Objective

To develop a body of fundamental knowledge relevant to potential problems involved in the application of chemical explosives to mining and related activities on the moon and other extraterrestrial environments, particularly with respect to the blast wave produced.

Summary

Scaling experiments have been performed in which the stagnation pressure profiles of the expanding products (blast wave) due to the detonation of an explosive charge in a vacuum have been measured.

Progress During the Year

Initial experiments to measure the stagnation pressure profiles of the products of an explosive charge detonated in a vacuum revealed a large number of sources of poor reproducibility, among which were: electrical noise from the firing circuit, electrical noise apparently generated by the detonation process, apparent differences in degree of acceleration compensation, rise time and ringing between gages, and apparently real inhomogeneity of the expanding products clouds. The first three sources were successfully eliminated; the last however, which must be due to turbulence or some unstable processes occurring in the expansion, perhaps occasionally to the projection of small particles of unreacted explosive, persisted throughout the experiment, even though the high-frequency components of the transducer output were electronically filtered.

Since the difficulties discribed above were more pronounced with the small, fast-rise-time pressure transducers originally used, most of the data was taken with a larger transducer fabricated with a quartz piezoelectric load cell as the active element; this transducer had a diaphragm diameter of 1.6 cm, and a rise time of ca. 5 μsec although it was found desirable to electronically smooth the signals to an effective rise time of 20 μsec. The charges fired were either pentolite spheres of 5.1 cm diameter, or pressed tetryl charges with diameters ranging from 1.9 to 7.6 cm (length-to-diameter ratio =1). The charges were fired in the 2.1-m-diameter, 11-m-long, 38,000-liter vacuum chamber at pressures of ca. 5×10^{-3} torr. The pressure transducers were stationed at scale distances of 7 to 35 cm/g$^{1/3}$ (scale distance is defined as the charge-to-transducer distance divided by the cube root of the charge mass).

With the spherical pentolite charges, the results obtained were found to be so inconsistent with each other and with measurements using cylindrical charges that they were discarded. The reason for this is not clear, since high-speed photographs of the breakout of detonation on the surface of the charge show very good simultaneity and reproducibility.

The data taken with the cylindrical tetryl charges showed that the peak stagnation pressures scaled as expected, approximately with the inverse cube of the scale distance, the leading edge of the blast wave having a constant velocity of ca. 10 Km/sec. This velocity is somewhat in excess of calculated values, which however are based on crude equations of state. It should be noted that no evidence of the existence of a wave of products having a leading-edge velocity of ca. 20 Km/sec was found in this experiment. This puts an upper limit on the density of the material causing the pink glow observed in framing camera experiments at ca. 0.002 times that of the slower blast wave observed in these experiments. At the larger scale distances the single pressure pulse begins to separate into multiple pressure waves. In some cases the separation between these waves is consistent with the ringing frequency of the transducer, but it is not clear why the amplitude or frequency of transducer ringing should be dependent on its location, so this phenomenon is attributed to unknown sources of instability in the expansion process.

Results were found to be insensitive to ambient pressure below ca. 5×10^{-2} torr even for the largest scale distances; therefore modification of the equipment and extension of the experiments to high vacua were considered unnecessary.

Status of Manuscripts

None scheduled.